Geoindicator Scoping Report for Fire Island National Seashore (Strategic Planning Goal Ib4)

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EXECUTIVE SUMMARY

The National Park Service (NPS) and U.S. Geological Survey held a scoping meeting for Fire Island National Seashore (FIIS), at Patchogue, New York, April 24-25, 2001. The purpose of the meeting was to bring together park staff, geoscientists, and other resource specialists to address the issue of human influences on geologic processes at FIIS. The group used institutional knowledge to inventory active geologic processes in the park and to identify known human activities affecting those processes, satisfying the first and second objectives of GPRA Goal Ib4, respectively. This summary report completes the objective of GPRA Goal Ib4 and is designed to be a tool for future FIIS management decisions as well as a pilot summary for similar coastal and barrier island parks within the NPS.

Major geologic processes occurring at Fire Island are being influenced by human activity. Humans have modified the barrier island landscape and consequently have modified its geologic system. This system is dynamic and capable of noticeable change within a human life span.

Geoindicators are measurable, quantifiable tools for monitoring rapid change in abiotic systems to help determine ecosystem health and stability. Of the 27 geoindicators, thirteen were selected as having significance to Fire Island National Seashore. The following four were identified as processes having the most ecological importance, the most widespread human influence, and the highest level of management significance to the park:

- **Shoreline position.** Beach replenishment (nourishment) and structural development such as jetties, bulkheads, marinas, and private homes significantly alter the natural shoreline.
- **Dune formation and reactivation.** The construction of roads and buildings, beach scraping, and secondary dune removal results in the destruction of vegetation and the destabilization of dunes making them more vulnerable to storm effects such overwash and flooding.
- **Wetlands extent, structure and hydrology.** The draining of wetlands for mosquito control, groundwater withdrawal, and the construction of bulkheads affect the hydrology, vegetation, and aerial extent of wetlands. This in turn promotes saltwater intrusion into freshwater wetlands, greatly altering the ecosystem.
- **Relative sea level.** Relative sea level rise alters the dynamics of the barrier island system. Factors contributing to the relative rise include: "autocompacting" of unconsolidated sediments, regional tectonics, groundwater withdrawal, isostatic rebound, sediment input, etc. The changes in compaction to barrier islands could affect groundwater level and quality, salt marshes, and wetlands.

The scoping meeting identified nine other geoindicators that are or have potential to become critical management issues for FIIS. These are: groundwater quality, groundwater level, groundwater chemistry in the unsaturated zone, wind erosion, surface water quality (William Floyd Estate), streamflow (William Floyd Estate), sediment sequence and composition, slope failure (landslides), and soil quality (William Floyd Estate). Managing mixed land ownership is the single most significant and difficult challenge to park management.

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1.0 RECOMMENDATIONS

1.1 Recommendations to Minimize Known Human Influences on Geologic Processes

Recommendations are not listed in order of priority. However, geoindicators that rated high for all three categories (natural process, human influence and management significance) might be used as a first cut for prioritizing projects.

- Continue to pursue a cooperative land protection program, including buyouts and land swaps, between FIIS and private communities. The long-term goal of redistribution of ownership on Fire Island is to relocate private homes to an area behind the primary dune system. Many homeowners are currently in violation of building and zoning regulations. This circumstance could be a potential benefit in pursuit of this goal.

- Continue to limit vehicular traffic on the beach and dunes for protection of native vegetation and the piping plover (*Charadrius melodus*).

- Continue to place emphasis on non-structural preservation activities as recommended in the Reformulation Study.

- Continue working with Army Corps of Engineers to replace dredged sand from inlets west of the natural sand barrier to promote east-west transport of sand (Bypass Plan).

- Pursue Disturbed Land Restoration funding for Otis Pike Wilderness Area for marsh restoration of mosquito ditches.

- Apply for Disturbed Lands Restoration funding to restore man-made artesian wells located throughout FIIS.

1.2 Recommendations to Increase Knowledge of Resources and Processes

1.2.1 Inventory Needs

- Obtain baseline inventory of marsh and wetland systems. Marshes are disappearing in a certain areas of the island. Is this due to human impacts? What are potential effects of relative sea level rise and resulting rise in groundwater levels on wetlands?

- Inventory non-native vegetation on a semi-annual basis to develop trends over time. Compare the effect of native vegetation with landscaped, non-native vegetation on maintaining dune systems and slowing erosional processes.

- Inventory non-native plant species on natural dune systems, primarily species planted on reconstructed dunes or as landscaping. Tie in to development of IPM plan.

- Inventory areas of reduced sand ("hot spots") to determine how they develop and migrate along the shoreline. Are certain areas always susceptible to erosion and are they always in the same location?

1.2.2 Monitoring Needs

- Develop data gathering methods other than historic time-lapse imagery and bathymetric surveys such as performing nearshore surveys using trained divers.

- Monitor bayside low-tide terrace benchmarks to determine if feature is advancing or retreating.

- Track sediment routing in bay following marina and landfill restoration project at Talisman/Barrett Beach.

- Train park staff to perform shoreline runs on a regular basis, borrowing protocols from the USGS.

- Continue measurement of shoreline with GPS before and after storm events in the Otis Pike Wilderness Area.

- Monitor flattened dunes and cross-island overwash at Old Inlet. Current monitoring is infrequent and limited to mapping of extent of inlet.

- Obtain dune crest and high water line information required by Vital Signs Monitoring, in conjunction with long-term transects to be measured periodically in future.

- Determine impacts of bayside bulkheads on park and community lands where bulkheads do not presently exist.

- Monitor the effects of depositing dredge spoils on East and West Fire Islands, including shoreline position and shoreline changes.

- Continue LIDAR surveys to monitor changes in dunes and repeat every two years.

- Monitor water level and water quality in the Sunken Forest.

- Monitor changes to marsh and wetland systems, once baseline inventory is established.

- Monitor groundwater levels and quality in the shallow lenses to determine the effects of septic systems on human health as relative sea level rises.

- Monitor changes in proliferation of *Phragmites australus* in wetland areas to help determine if encroachment is a potential management problem.

1.2.3 Research Possibilities

- Research long-standing, key questions of mechanisms for nearshore Cretaceous sediment delivery on-shore, for hydrodynamic movement, and for sediment flux through the zero-to-minus-ten-meter depth.

- Research the effect of the offshore Cretaceous sand ridges on shoreline erosion. Do they channel wave energy towards specific sections of beach, as suspected?

- Take advantage of Vital Signs funding to implement shoreline position change research. Both ocean and bay shorelines need to be considered when examining shoreline change.

- Research the Westhampton groin field to determine downshore effects.

- Research effects, if any, that the garnet and magnetite-rich sands have to the system?

- Research effect of reintroducing sand to Cretaceous structure off Watch Hill Point or into the sub-sea sand ridges.

- Continue to seek funding for research on sea level rise and impacts to salt water marshes and herpetological populations.

- Obtain quantitative data on how storm events impact primary dunes vs. manmade dunes.

- Research the effects of beach replenishment on dune morphology and longevity.

- Research the nature and effects of wave action on man-made dunes following beach scraping. Determine whether beach scraping (i.e., artificial dune construction) is causing changes in wave height, wave direction, and/or wave intensity.

- Continue research on effect of exclosures on deer browse disturbance in the Sunken Forest. What effect does browse disturbance by deer have on the native vegetation on the island outside the Sunken Forest? Do deer selectively browse native vegetation?

- Research the effects dune formation and shoreline position have on drainage patterns.

- Research the effects of creating islands from dredge spoils on flora and fauna. Does habitat created for shorebirds and other creatures outweigh possible negative consequences?

2.0 Introduction

Natural processes operating at the land surface make life possible but also pose threats to that life. Those natural processes include geologic processes such as erosion, deposition, weathering, mass movement, tectonism, and volcanism. Some of the hazards they produce take place rapidly, such as landslides, rock falls, dust storms and floods. Others may be more gradual events, such as topsoil erosion, changes in streamflow, and contamination of water and soil. The technical knowledge now exists to support real progress in comprehending the fundamental nature of these various surficial processes, their rates and effect, and their response to natural and human-caused changes. Our society has a great need for improving knowledge of surficial processes. The continued shortsighted use of natural resources is threatening the long-term welfare of the earth's ecosystems (Wilshire, *et al*., 1996). The National Park Service (NPS) strives to preserve natural resources and processes, and therefore needs to understand the changes caused by human activities.

It may be difficult in any particular environment or ecosystem to separate the anthropogenic influences from the natural geologic ones. The concept of "geoindicators" was designed to assist in this task. The basic tool is a checklist of geological indicators of rapid environmental change. The list includes 27 natural system processes and phenomena that are likely to change in magnitude, direction, and rate. These are changes that are limited to those that can occur within a human life span and, to an extent, those that may be of significance to ecological health. Geoindicators have been developed as tools to assist in integrated assessments of natural ecosystems as well as for state-of-the-environment reporting. They describe common earth processes that operate in one or more physiographic settings, and that collectively represent a landscape measurement, one that concentrates on the non-living component of the ecosystem and its interactions with the biologic and human components.

2.1 GRPA Goal Background

In 1999, the Geologic Resources Division and the NPS Strategic Planning Office cooperated to develop a Servicewide geologic resource goal (Goal Ib4) as part of complying with the Government Performance and Results Act (GPRA). This goal states, "Geological processes in 53 parks [20% of 265 parks] are inventoried and human influences that affect those processes are identified." This goal is designed to improve park capabilities to make more informed science based management decisions. It was the intention of the team that designed this goal that it be the first step in a process that would eventually lead to the mitigation or elimination of human activities that severely impact geologic processes, harm geologic features or cause critical imbalance in the ecosystem.

2.2 Park Selection

Fire Island National Seashore (FIIS) was selected to participate in the scoping process because the park protects the barrier island and coastal geologic resources and processes which have nevertheless been extensively disturbed by human activity. The decision was also due in part to enthusiasm by the superintendent and the Chief of Resources Management to host the scoping meeting. The information gathered at FIIS may be applicable to other coastal and barrier island parks with similar resources and issues and thus may have Servicewide implications.

2.3 Role of Geology in the Ecosystem

The geologic resources of a park – soils, caves, fossils, streams, dunes, volcanoes, etc. – provide a set of physical conditions necessary to sustain the biological system. Interference with geologic processes and alteration of geologic features inevitably affect habitat conditions. For example, the channelization of the Virgin River in Zion National Park caused the channel to incise, lowering the groundwater table and reducing the habitat of floodplain obligate species (Steen, 1999). For a more detailed discussion of geologic processes and the role in the ecosystem see Appendix 1 and Appendix 4.

2.4 Geoindicator Background

In a particular ecosystem, it is often difficult to separate human influences from natural geologic ones. To assist in distinguishing these influences, the concept of "geoindicators" was introduced to NPS resource management as a new ecosystem management tool for park planning in 2000. The basic geoindicators tool is a checklist of geological indicators of rapid environmental change. These indicators, developed by the International Union of Geological Sciences, provide a science-based method to assess rapid changes in the natural environment.

The list includes 27 earth system processes and phenomena that may undergo significant change in magnitude, frequency, trend, or rates over periods of 100 years or less and may be affected by human actions (Appendix 3, Table 1). Some are single parameters, such as shoreline position, and others are aggregates of several measures such as groundwater quality. Other examples include streamflow and channel morphology, groundwater level, soil and sediment erosion, frozen ground activity, lake level and salinity, and slope stability.

Geoindicators measure both catastrophic events and those that are more gradual, but evident within a human life span. To an extent, geoindicators may be a measure of ecological health. The NPS uses the geoindicators concept as the basis for discussing and evaluating the state of the environment, ecosystem changes and how humans are affecting natural systems. Geoindicators are an invaluable tool to help focus non-geoscientists on key geologic issues, help parks anticipate what changes might occur in the future and identify potential management concerns from a geologic perspective.

The NPS uses geoindicators as a proxy for geologic process. Geoindicators are not geologic processes. However, there is a strong correlation between the two (Appendix 3). Because geoindicators represent a landscape measurement, one that concentrates on physical processes and their interactions with biologic and human components, they are uniquely suited to assess human vs. natural causes of change in the ecosystem.

2.5 Park Setting and Natural Resources

2.5.1 Setting

Fire Island National Seashore includes a 32-mile long barrier island located south of and parallel to Long Island, New York (Figure 1). The island is variable in width with a maximum of approximately 2,000 feet. Also included as a unit of FIIS is the William Floyd Estate, a 613-acre unit located in the hamlet of Mastic Beach on the south shore of Long Island. The estate is listed on the National Register for its significance as the home of General William Floyd, a signer of the Declaration of Independence, and for its continuous 250-year occupancy by the Floyd family since it was built by Nicoll Floyd in 1724. More than two million people visit the seashore annually. Most park visitors utilize the eastern and western ends of the park which are easily accessed by automobile. Nevertheless, tens of thousands of annual visitors use facilities in areas primarily accessed by boat or ferry.

2.5.2 Vegetation and Soils

Primary dunes on the barrier island are generally vegetated with American beach grass (*Ammophila breviligulata*), although other species, including seaside broomspurge (*Euphorbia polygonifolia*) and beach plum (*Prunus maritima*), also may be present. Vegetation on foredunes is generally sparse, although some species, such as beach grass, seaside goldenrod (*Solidago sempervirens*), and sea rocket (*Cakile maritima*), may be present. Foredunes provide habitat used extensively by nesting shorebirds. Shrubs give rise to thickets and eventually are replaced by holly and hardwood maritime forests. The park protects a 300-year-old holly and sassafras forest called the Sunken Forest. Trees in the forest are pruned by salt air and driving winds to the height of the primary dune. The forest is a haven for an abundant deer population.

Secondary dunes, or back dunes, are the dunes farthest from the ocean and are located behind the primary dunes. Vegetation on secondary dunes may include beach grass, seaside goldenrod, and other herbs, but may be dominated by low-growing, woody shrubs and trees, including beach plum, poison ivy (*Toxicodendron radicans*), wild rose, and pitch pine. As the plant cover on secondary dunes progresses from sparse grasses and herbs to dense woody vegetation, secondary dunes become relatively stable and more resistant to wind and water erosion. Secondary dunes, particularly in areas dominated by shrubby vegetation, provide foraging and nesting habitat for a variety of wildlife, including songbirds, reptiles, small mammals, and deer.

Swales are depressions between dunes. Swales may be vegetated with a variety of grasses, herbs, and shrubs, including beach grass, seaside goldenrod, poison ivy, and beach plum. In some locations, particularly where coastal waves have overwashed primary dunes, swales may be relatively free of vegetation and such areas also provide habitat for nesting shorebirds.

The ocean coastline of the barrier island is unvegetated beach except for the natural dunes present along the entire stretch beach. There are also unvegetated bay side beaches. Some of these beaches grade into submerged shoals that extend into the water for about 300 feet. Shoals are generally unvegetated with a maximum depth of about two feet below mean sea level. Mean tidal range in Great South Bay varies from about 0.7 to 1.4 feet. Shoals eventually meet the bay bottom at a depth of approximately four to six feet below mean sea level. Some deepwater habitats in the park are generally vegetated by eelgrass (*Zostera marina*) in low to medium densities (Raposa and Oviatt, 1997).

Three types of soils are present on the barrier island including beach, dune land, and fill land. The William Floyd Estate on Long Island has developed topsoil and subsoil systems which support pine oak forest communities.

2.5.3 Aquatic Resources

The park protects wetlands, deepwater habitats, salt water marshes and bays, and the water under the jurisdiction of the United States. The William Floyd Estate protects 175 acres of coastal salt marsh, four man-made ponds (salt and freshwater) and several small streams. Tidal marshes occur in various areas of the park, with the most prevalent within the federally designated Otis Pike Wilderness Area. The boundaries of the Seashore encompass approximately 20,000 acres, including open-water areas south of the park up to 1,000 feet into the Atlantic Ocean and north of the park up to 4,000 feet into the Great South Bay.

The most common fish in the waters off the island are silverside (*Menidia menidia*), bay anchovy (*Anchoa mitchilli*), mummichog (*Fundulus heteroclitus*), and striped killifish (*Fundulus majalis*). Other common aquatic species in the area include sand shrimp (*Crangon septemspinosa*), grass shrimp (*Paleomonetes pugio*), and a variety of snails, clams, and mussels. Ducks and geese, including scaups (*Aythya* sp.), scoters (*Melanitta* sp.), oldsquaws (*Clangula hyemalis*), and Brant geese (*Branta bernicla*), feed in the area.

According to the National Marine Fisheries Service (NMFS), the waters of Great South Bay in the project area have been designated as “essential fish habitat” for 15 species of managed fish. Essential fish habitat comprises “those waters and substrates necessary to fish for spawning, breeding, feeding, or growth to maturity” (Magnuson-Stevens Fishery Conservation and Management Act, as amended, PL 94-265; Apr. 13, 1976, 90 Stat. 331; 16 USC §1801et seq.)

2.5.4 Wetlands

The park has an inventory of the limits of wetlands as determined in accordance with NPS Procedural Manual 77-1, *Wetland Protection* (NPS 77-1), which implements Executive Order 11990, *Protection of Wetlands*. NPS 77-1 utilizes the methodology of the U.S. Fish and Wildlife Service as a departmental standard for classifying and inventorying wetlands and for determining the extent of wetlands (USFWS, 1979). The limits of jurisdictional waters were determined in accordance with the Army Corps of Engineers (ACE) regulatory program under 40 CFR 110 *et seq.*, the Clean Water Act of 1972, and the Rivers and Harbors Act of 1899, as amended.

According to NPS criteria, wetlands must have wetland hydrology, that is, a water table that is usually at or near the ground surface or a land surface covered by water. Also, the wetland must support wetland vegetation and/or hydric soils and/or a non-soil substrate that is saturated or covered by shallow water at some time during the growing season (USFWS, 1979). Deepwater habitats in marine systems include permanently flooded, subtidal areas seaward of wetlands.

Under NPS criteria, unvegetated, tidally influenced beaches and rocky shores would be considered wetlands, while permanently inundated areas would be considered deepwater habitats.

According to Corps criteria, jurisdictional wetlands must have wetland hydrology, wetland vegetation, and hydric soils. Although the Corps would not consider sandy beaches to be "wetlands", all beach areas below the high tide line would be considered jurisdictional waters. Permanently flooded marine habitats in the project area also would be considered jurisdictional waters and would be subject to the Corps' regulatory program under the Clean Water Act of 1972, as amended, and the Rivers and Harbors Act of 1899, as amended.

2.5.5 Water Quality

Data collected from 1977 through 1997 indicate that water quality in the Great South Bay is impaired (NPS-WRD Listed Waterbodies with Impaired Waters). Throughout the monitoring period, more than 2,600 water samples were collected and analyzed from 20 locations in Great South Bay. Data collected at sampling stations included concentrations of nitrogen, phosphorous, dissolved oxygen, salinity, coliform bacteria, chlorophyll-a, and *Aureococcus anophagefferens*, the organism that causes brown tides in the bay.

Water transparency also was measured at each station. Water transparency, which is a measure of the distance that light is transmitted through water, may be reduced by a variety of factors, including increased concentrations of suspended and dissolved materials. In addition to Great South Bay, water quality also was evaluated in Moriches Bay and Shinnecock Bay during the same monitoring period. During the monitoring period, no dramatic trends in water quality were apparent in Great South Bay, although most variables exhibited great annual variation. The most consistent trend over time was increased nitrogen in the bay with highest concentrations generally along the bay's north shore.

Residents on Fire Island utilize a source of groundwater nearly 2,000 feet deep in sedimentary rock. A shallower groundwater lens exists, but is not used for human consumption. The barrier island surface is composed entirely of sand, and water readily percolates through it. No streams or other fresh surface water exists on the island.

2.5.6 Wildlife

A variety of wildlife utilizes sand dunes in the park. Some species such as least tern (*Sterna antillarum*) and piping plover (*Charadrius melodus*) are most common in nesting areas on and near the toes of foredunes. Other species are more common in other areas, including migratory birds (towhee, thrasher, warbler, and song sparrow), mammals (cottontail rabbit, white-footed mouse, red fox, and white-tailed deer), reptiles (hog-nosed snake and black snake), and invertebrates (ticks, grasshoppers, and monarch butterfly).

Wildlife inhabiting the tidal zone along sandy beaches in the project area includes gulls and shorebirds, such as greater yellow legs (*Tringa melanoleuca*), dowitchers (*Limnodromus* sp.), piping plover, and sanderling (*Caladris alba*) along with the hundreds of species of invertebrates that make up the food source for birds and other wildlife.

There are a total of 28 state and federally listed species that occur within the boundaries of Fire Island National Seashore. One species of amphibian, six reptile species, eight bird species and 13 mammal species (FIIS Position Paper on Endangered Species Management, 2000 [Unpublished]) Federally-listed species that consistently use park habitat are the piping plover (*Charadrius melodus*) and the seabeach amaranth (*Amaranthus pumilis*). The federally-listed endangered roseate tern *(Sterna dougalli*) was sighted in 1993 through 1995 when habitat monitors were trained to look for this shorebird, but it has not been observed to breed on Fire Island. A fourth species, the northeast beach tiger beetle *(Cicindela dorsalis dorsalis)*, has not been sighted on Fire Island within the recent past, but has been restored to nearby areas and could potentially be found on Fire Island.

The park is also required to protect New York State listed wildlife, in accordance with the Endangered Species Act: "In carrying out the program authorized by this Act, the Secretary [of the Interior] shall cooperate to the maximum extent practicable with the States." (Section 6[a]) State-listed species that use park habitat include the common tern, (*Sterna hirundo*), least terns (*Sterna albifons*), and seabeach knotweed (*Polygonum glaucum*).

2.5.7 Legislative-Regulatory Summary

Barrier Island

Fire Island is one of the northernmost barrier islands managed by the NPS in a chain that stretches from Cape Cod to Florida. In 1964, under Public Law 88-587, Congress designated approximately 26 miles of Fire Island as Fire Island National Seashore "for the purpose of conserving and preserving...certain relatively unspoiled and undeveloped beaches, dunes, and other natural features...which possess high values to the Nation as examples of unspoiled areas of great natural beauty in close proximity to large concentrations of urban population..." (Public Law 88-587, §1(a), September 11,1964).

Park boundaries included waters surrounding the area to distances of one thousand feet in the Atlantic Ocean and up to four thousand feet in Great South Bay and Moriches Bay. Boundaries included not only Fire Island proper, but also marshlands and wetlands in the Great South Bay, Narrows Bay, and Moriches Bay adjacent to Fire Island. Also within the boundaries were islands adjacent to Fire Island including Sexton Island, West Fire Island, East Fire Island, Hollins Island, Ridge Island, Pelican Island, John Boyle Island, Pattersquash Island, and Reeves Island. Of the approximately 20,000 acres of FIIS, only about 6,200 acres are federally owned. Land area is about 16,500 acres (Figure 2).

Figure 1 Location of Fire Island National Seashore

Section 7(a) of PL 88-587 states that "[t]he Secretary shall administer and protect the Fire Island National Seashore with the primary aim of conserving the natural resources located there." Still, there are unusual requirements in Sections 8(a) and (b), “Shore Erosion Control.” Section 8(a) states, “The authority of the Chief of Engineers, Department of the Army, to undertake or contribute to shore erosion control or beach protection measures on lands within the Fire Island National Seashore shall be exercised in accordance with a plan that is mutually acceptable to the Secretary of the Interior and the Secretary of the Army…” Section 8(b) says, “[t]he Secretary shall also contribute the necessary land which may be required at any future date for the construction of the new inlet across Fire Island in such location as may be feasible in accordance with plans for such an inlet which are mutually acceptable to the Secretary of the Interior and the Secretary of the Army…”

The Corps of Engineers is a powerful influence generally backed by the Fire Island communities and often has management goals contrary to those of the NPS, especially regarding breach closure and beach replenishment. The park is unique in that it preserves the last developed barrier island in the United States that does not support a system of continuous roads. There are no public roads within the 32-mile-long stretch of Fire Island under NPS jurisdiction.

William Floyd Estate

In 1965, a donation was accepted by the Secretary of the Interior under Public Law 89-244 (October 9, 1965) which designated 611 acres of land, "submerged lands, islands, and marshlands" and the main dwelling of General William Floyd as a detached unit of Fire Island National Seashore. The estate is located in the hamlet of Mastic Beach on the south shore of Long Island. Prior to the late nineteenth century the Estate was a “northern plantation” that produced crops and livestock for barter and cash. Currently the estate is compromised of 175 acres of coastal salt marsh; 80 acres of managed old fields and turf grass, 8.5 miles of wooded trails and approximately 360 acres of woodlands.

Otis Pike Wilderness Area

Fire Island National Seashore protects a seven-mile stretch that is the only federal wilderness area in New York state. Under Public Law 96-585 (December 23, 1980), Congress designated 1,363 acres of Fire Island National Seashore as the Otis Pike Fire Island High Dune Wilderness, or more commonly, the Otis Pike Wilderness Area. A significant aspect of the enabling legislation for the seven-mile stretch of wilderness area specifies that the park shall not preclude closing of breaches or inlets as they form even if they would naturally remain open. Paragraph (c) of the Act states that “the Secretary shall administer such lands in such manner as to preserve, insofar as possible, their wilderness or potential wilderness character.” Paragraph (d) states, “[w]ilderness designation shall not preclude the repair of breaches that occur in the wilderness area, in order to prevent loss of life, flooding, and other severe economic and physical damage to the Great South Bay and other surrounding areas.”

The decision to create the wilderness area was driven more by politics than by resource protection, as it was simply the last remaining area on Fire Island that was not developed. The park had intended to develop the area for major recreational facilities such as marina construction. The goal of the residents was to preserve the island's natural features and protect it from overuse, which in this case meant protect it from NPS recreational development.

Based on the 1997 ACE Interim Breach Management Plan, any breach that develops within the wilderness area will be monitored through 72 hours of tide cycles to see if it will close naturally without human interference. If the breach continues to widen after 72 hours, the NPS is mandated to allow the ACE access to close the breach. Once the ACE Reformulation Plan is approved by the Department of Interior, the Interim Breach Management Plan is no longer valid as a management tool.

The reasons for this unusual mandate are to preserve the economy of the Great South Bay, such as fishing, and to protect private property and dwellings on Fire Island and Long Island. Allowing natural processes to occur is normally a fundamental NPS mandate. Based on the mandate in the wilderness area, the park is faced with limited management choices concerning breach closure. Hence, it is possible to interpret this as conflicting with the enabling legislation for the Seashore, which states that land shall be made available for inlets and other natural processes to take place.

2.5.8 Land Use History

Land ownership on Fire Island is divided into strips of private and public land in a complex land-use pattern (Figure 2). Within park boundaries are numerous private properties arranged in larger communities. Each community has its own regulations, and, depending on the community, residents may or may not own the land on which they live. Since the 1950s, private individuals have developed homes and communities on these private lands. These private communities were well-established prior to creation of the park in 1964.

There are also a number of individual private inholdings inside the park. Many communities are developed in European-style density which has resulted in over 4,000 homes on approximately seven linear miles of barrier island, not including the intervening lands under NPS jurisdiction. These homes range in value from about $250,000 to several millions of dollars. The homeowners carry substantial economic and political clout. NPS management decisions, especially concerning breach closures, affect not only residents of Fire Island, but also residents of Long Island to the north across Great South Bay.

In addition to private inholdings, Smith Point County Park is located inside the park boundary on the easternmost end of Fire Island. This park is managed by Suffolk County with different recreation and land-use mandates than those required of Fire Island National Seashore.

On April 4, 2001 the National Parks Conservation Association (NPCA) released a Special Alert ranking Fire Island National Seashore third on their list of the ten most endangered national parks. The Special Alert is associated with the ACE Storm Damage Reduction, Reformulation Plan. The project is designed to replenish sand eroded during periodic winter storms and reconstruct dunes using sand from external sources such as from offshore. This activity potentially threatens the integrity of the national seashore. Beach nourishment (or replenishment) is generally supported by the residents living in communities on the island. Their interest in the project is obvious since homes on the island are threatened by the continuous erosion and accretion of the island, natural barrier island processes. The NPCA recommends authorizing sufficient funds to allow the NPS to acquire private parcels in the dune systems. It also recommends giving the NPS the authority to stop new building or rebuilding in dune areas.

Fire Island National Seashore managers struggle with the mandate to manage a shifting, highly dynamic barrier island in a static way by closing breaches which occur naturally. At the same time, they try to work with the ACE and community members who feel it is necessary to deal with the shifting, dynamic landscape in a static way. On the one side are resource protection and the recognition that all barrier islands shift, migrate, disappear and reform. On the other, are the social, political, and economic forces that, result in the continued management of the island for the benefit of special interests. The resolution of this dilemma may occur only when the costs of holding the island fixed (eg., insurance, beach replenishment, repair and rebuilding structures, loss of life, etc.) become prohibitive.

Figure 2: Fire Island National Seashore

2.6 Geologic Setting

Fire Island is located at the terminal moraine of the Laurentian ice sheet. The glacier began its retreat 8,000-12,000 years ago, and residual material supplies the garnet and magnetite sand found on the island. The sediments comprising Fire Island National Seashore and the south shore of Long Island are largely derived from reworking of Pleistocene sediments. These sediments were either deposited directly by the Laurentide glacial event or from glacial drift deposited offshore during a period of sea level rise in the Holocene period of the last 18,000 years. Similar material may be found in the Ronkonkama moraine exposed near Montauk Point about 100 km to the east. The occurrence of the heavy mineral fraction in the otherwise silica and feldspar dominated sediment lends support to a glacial source. Glauconite is absent from the glacial till and outwash sediments off of the eastern two-thirds of Long Island, but is abundant off unglaciated New Jersey about 50 miles to the southwest. Glauconite is almost exclusively of marine origin. It is a mica mineral formed authigenically either from the alteration of biotite or from an aluminosilicate gel. Magnetite and feldspar are common on Long Island but not in New Jersey (Williams and Meisburger, 1987).

Sea level rise during deglaciation slowed about 9,000 years ago and may have led to the development of ancestral barriers (Schwab, *et al*., 2000). A decrease in the rate of sea level rise about 4,000 years ago favored more growth of barrier islands. Continued rise in relative sea level forced these islands to migrate onshore, especially to the east where the offshore slope is steeper and inlets are more frequent. As a result, the larger barrier lagoon is located to the west, and smaller lagoons are found to the east. At the same time, obliquely incident waves created a net littoral drift of sediment to the west, resulting in westward spit extension and inlet migration.

At present the central portion of the barrier is the oldest, about 1200 years old (Leatherman and Allen, 1985). Inlet dominated transgression is more frequent at the eastern part of the island with salt marshes occurring on old flood tidal deltas. A prograding spit with recurved dunes occurs to the west. Democrat Point was "stabilized" by a terminal jetty in 1940, but the adjacent Fire Island Inlet requires dredging to provide navigational access. The regional longshore sediment transport rate has been estimated at 70,000 m^3 per year from the headlands, increasing to roughly 200,000 m^3 per year along the barrier islands and inlets east of Fire Island. Sediment transport increases to 400,000 m^3 per year at Fire Island Inlet. The local increase along the western half of Fire Island has been attributed to the shedding of sediment from the remnants of a Cretaceous-age outcrop offshore of Watch Hill near the center of Fire Island (Schwab et al., 2000). Onshore flux is manifested by oblique sand ridges 10-30 meters deep. These ridges appear to be associated with patterns of shoreline change on the order of decades and with dune erosion during very large storm events (Allen and LaBash, 1997; Schwab, *et al*., 2000).

The area is very well studied in terms of geological evolution, albeit with contentious issues of timing and relict offshore expressions (Taney, 1961; Leatherman and Allen, 1985; Williams and Meisburger, 1987; Rampino and Saunders, 1981; Paneogtou and Leatherman, 1986). Fire Island has rich history of inlet development with one of the best sets of digital data in the nation describing shoreline change over the past century (Leatherman and Allen, 1985). Since 1993, this has been augmented by GPS surveys of shoreline position at annual to seasonal intervals (with one storm impact) along the full length of the island. Historically Fire Island has always been bounded on the west by Democrat Point and by Fire Island Inlet. Fire Island Inlet migrated about 64 meters per year westward until construction of a jetty.

Old Inlet was open from about 1750 to nearly 1830 in the present Wilderness Area, about 15 kilometers west of the present eastern end (Figure 2). From 1830 to 1932, the barrier chain was a continuous spit until Moriches Inlet formed. During this period there was a major advance in the shoreline near Old Inlet. What once was the old foredune now is a secondary dune. The formation of Moriches Inlet led to the interruption of longshore sediment transport and the development of flood tidal shoals. The inlet migrated westward a few kilometers and started to close by 1950. By 1953 it was reopened by dredging, and a jetty was constructed for navigational access. The inlet then shifted into an ebb-dominated regime accompanied by the growth of an ebb-tidal delta. Shoreline change between 1933 and 1979 shows the sediment deficit effect of the inlet. 120 meters of erosion occurred downdrift of the inlet which then transitioned to no net change about 14 kilometers downdrift. The center of the island again prograded resulting in major sediment accumulation at the Democrat Point jetty.

Dune crestline positions were mapped in 1976, 1981, 1986, and in late November and late December 1992. The mapping identified a series of nested hierarchies of crestal change responding to both natural and anthropogenic effects on dune morphology (Psuty and Allen, 1993). The data are vertically controlled by annual topographic surveys of 28 profiles between Kismet (to the west) and Watch Hill (Figure 2) and by detailed 3-D surveys of dunal change just west of Kismet and in front of the Talisman-Barrett Beach area (Allen *et al*., 2001).

Recent comparisons of GPS surveys with NOAA "T" Sheets and aerial photography updated work by Leatherman and Allen (1985) documenting recent evolution of the island (Allen *et al*., 2001). After accumulating a volume of about 2.3 million cubic meters of sediment between 1986 and 1994, the ebb-tidal delta off of Moriches Inlet began bypassing sediment to Fire Island. About 2 kilometers downdrift, the beach accreted 120 meters since 1979. An erosional shadow still existed up to about 15 kilometers west of the inlet. The center of the island still accreted but the eastern half displayed very high frequency variability. The western half of the island possessed a pattern of very large "wave forms" of erosion and accretion at about 6 kilometer intervals in front of the resident communities.

These spatially periodic features of shoreline change are not only related to natural dispersion of sediment inputs but also to offshore controls upon incident wave energy and cross-shore sediment transport (Gravens, 1999). Allen and Psuty (1987) argued that the development of gaps in the prominent longshore bar and trough morphology are contributing factors to localized beach and dune erosion. Schwab, *et al*. (2000) suggest that the offshore ridges may also be linked to the erosion.

The December 1992 storm had over 10 high tides with greater than 0.3 meter storm surge as measured nearby at Sandy Hook. The storm has a recurrence interval of about 25 years, but a very long duration. Local cells of erosion migrate westward yielding a waxing and waning episode to shoreline change direction. These erosion cells have a persistence time of months to possibly years.

From 1870 to1979, there was an island-wide mean rate of shoreline retreat of 0.44 meters per year. Spatial variability at both long and short time intervals dominates the simple central tendency. This confounds engineers, planners, and others attempting to remedy impacts of coastal retreat on the communities surrounding Great South Bay behind Fire Island. For decades there has existed a conflict between the Department of the Interior and the Army Corps of Engineers as to how to provide storm damage protection along the south shore of Long Island.

In 1978 the Council on Environmental Quality ordered a Reformulation Study which led to a flurry of research in the early 1980s. During the 1990s, the NPS continued research on shoreline change and breaching threats. In response to storm damages in the early 1990s, the New York Planning District of the ACE initiated an "interim" project of beach nourishment and dune rebuilding in 1996. This led to an announcement by the NPCA in April 2001 that Fire Island is one of the nation's "10 most threatened parks."

Geologic resources are unique features of the dynamic coastal environment. But as changes occur, so does the utilization of the resource both by humans and by many other species. Special attention is given to those species that have Threatened and Endangered status. On the beach this includes piping plover, seabeach amaranth, the Northeastern tiger beetle, and various other listed species that utilize the offshore area of Fire Island and/or are migratory species using the offshore or island habitat .

Principal competitors for habitat space of these species are human recreational activities aggravated by the fact that Fire Island is the only developed barrier island in the nation without a central roadway. The beach is the highway for all vehicular access, including federal and county safety patrols, utility suppliers, maintenance of power and telephones, local contractors, local residential traffic and 4-wheel drive school buses. The beach is utilized far beyond its role as an energy buffering function of sand vs. waves. Dunes are more than just repositories of aeolian sediment taken from the beach. They also provide flood protection for the island and protect the mainland from flooding overwash and breaching events. At Fire Island the geological resources are functionally tied into the culture of modern, coastal development in America. Although other coastal parks are also impacted by development, none have the proximity to one of the world's largest urban areas as does Fire Island.

Littoral Processes

Littoral processes include the interaction of waves, currents, winds, tides, sediments, and other materials near the shoreline. Littoral currents flow either parallel to the shoreline (*e.g.*, longshore currents) or perpendicular to the shoreline (rip currents or undertow). Littoral currents along Fire Island generally run in an east-west direction. Together with waves, winds, and tides, littoral currents transport coastal materials towards and away from beaches. Such materials, collectively referred to as littoral drift, include sand, gravel, other sediments, and organic material. Littoral transport is the movement of littoral drift in the littoral zone by waves and currents. Depending on the rate and direction of littoral transport, beaches erode, accrete, or remain relatively stable.

Waves are the primary cause of sediment transport in the littoral zone and are the principal cause of most shoreline change. A variety of factors influence the direction and energy of waves, including wind and water depth. In shallower waters, the energy of waves is dissipated through friction with bottom sediments and additional energy is lost as waves break on shorelines or other objects. In general, waves that approach shore through deeper water or channels retain greater energy that is spent in closer proximity to the shore. When greater energy is expended by waves in the littoral zone, erosive forces increase the transport of littoral drift.

Structures that extend perpendicular to shorelines interfere with natural littoral processes and sediment transport. For example, groins are constructed to control or modify littoral transport. Such structures block the nearshore movement of littoral materials and cause “up-current” beaches to accrete. Although groins may increase deposition on up-current beaches, they effectively steal sediments from down-current beaches, intensifying erosion in those areas.

3.0 RESULTS OF GEOINDICATORS SCOPING MEETING

A geoindicators scoping meeting was held at Fire Island National Seashore at Patchogue, NY, April 24-25, 2001. The purposes of the scoping session were to determine the significant geologic processes that shape the ecosystems of the park and to identify the human influences on those processes. Evaluation of human influences in parks encompasses not only visitor impacts, but park management practices and developments, land use adjacent to parks (e.g., urbanization, and recreational uses), and global issues (e.g., global warming and sea level rise).

3.1 Geologic Processes

Table 1 lists the geoindicators identified at Fire Island National Seashore. These geoindicators were adapted from Berger (1995) and are considered a proxy for geologic processes. The scoping group rated the significance of each geoindicator to the park, the influence of human activity on the geologic process, and the significance to park management. Each geoindicator is given a rating of high, medium, and low. The scoping group identified thirteen geologic processes that occur in the park. Eight of these geologic processes were considered to be highly significant to the park ecosystems .

Human influences in parks includes not only visitor impacts, but also internal park management practices and developments, as well as land use adjacent to parks. Human influence on geologic processes was ranked high for nine geoindicators. Four of them relate to the morphology of the barrier island, such as dune activity and shoreline processes. Since a great deal of vehicular activity takes place on the beach and dunes, the human impact is considerable.

3.2 Results of Scoping Meeting

3.2.1 Field trip

During the morning field trip to West Fire Island, meeting participants drove through communities on West Fire Island to better understand the density of development in those communities. Many homes are extremely close together, some within 10-20 feet on all sides. Many homes were constructed directly on dune fields and had septic systems of questionable construction, and many were landscaped with exotic vegetation.

The difference between natural dunes and manmade dunes constructed by bulldozers was apparent in their size, shape, erosion characteristics, color, texture, and vegetation. In the Sunken Forest area, there is a visible difference in the vegetation which occupies the area between the primary and secondary dunes. At the Ocean Beach community, two groins are in disrepair. They were originally constructed to protect a water tower, which has since been moved. The dredging of spoils from Great South Bay has created several low-lying islands which are under NPS jurisdiction.

Although there are no public roads on the island, driving on the beach is permitted, as witnessed by many vehicle tracks on the beach, along with cuts in the dune fields to allow vehicle access to the beach. A ban on driving within communities has caused one community to construct a narrow gauge railroad for shuttling supplies from ferry docking facilities to a distribution area in town.

3.2.2 Scoping Meeting

The scoping group identified thirteen geoindicators as relevant to the park (Table 1). Nine of these were considered to have fundamental importance to FIIS ecosystems. Four were identified as processes having the most ecological importance, the most widespread human influence, and the highest level of management significance to the park. These are: dune formation and reactivation, shoreline position, wetlands extent, structure and hydrology, and relative sea level. Table 1 shows the ranking of the selected geoindicators for Fire Island. These are a subset of the of twenty-seven geoindicators developed by the International Union of Geologic Sciences (Table 2, Appendix 3). Although these processes are found on many other barrier islands, these thirteen geoindicators are specific to FIIS.

Meeting participants considered the barrier island ecosystem separately from the William Floyd Estate, and gave each separate rankings. Findings for the estate are shown in the smaller section below the main table in Table 1. Table 1 uses limited existing data based on the institutional knowledge of meeting participants and not necessarily on current research data.

Table 1: Selected Geoindicators and Their Ecological Importance, Degree of Human Influence, and Management Significance at Fire Island National Seashore.

Geoindicators Identified in the FIIS Barrier Island Ecosystem	How important is the process to the park's ecosystem?	Rank the human impact on the geologic process	Significance to park management
Arid and Semi-Arid			
Dune formation and reactivation	**H**	**H**	**H**
Wind erosion	**H**	**H**	L
Coastal			
Relative sea level	**H**	**H**	**H**
Shoreline position	**H**	**H**	**H**
Groundwater			
Groundwater chemistry in the unsaturated zone	L	L	L
Groundwater level	M	L	M
Groundwater quality	**H**	**H**	M
Surface water			
Surface water quality	L	L	L
Wetlands extent, structure, and hydrology	**H**	**H**	**H**
Hazards			
Slope failure (landslides)	L	**H**	L
Other (multiple environment)			
Sediment sequence and composition	M	**H**	L

Geoindicators Identified in the William Floyd Estate	How important is the process to the park's ecosystem?	Rank the human impact on the geologic process	Significance to park management
Surface water			
Surface water quality (two streams, one pond)	**H**	**H**	M
Streamflow	**H**	M	M
Other (multiple environment)			
Soil quality	L	L	L

H-HIGHLY influenced by, or with important utility for M-MODERATELY influenced by, or has some utility for L-LOW or no substantial influence on, or utility for

3.3 Description of Geoindicators for Fire Island

3.3.1 Dune Formation and Reactivation

Ecological Importance

Sand dunes typically provide a transition from coastal beaches to upland areas on the island and comprise primary dunes, foredunes, swales, and secondary dunes. Primary dunes are closest to the ocean and are formed as wind-blown sand accumulates at the base of vegetation and beach debris. Foredunes compose the ocean-facing side of primary dunes and are dynamic areas that change frequently according to weather, wind, and human activity.

Coastal dunes are important determinants of coastal stability as they supply, store, and receive sand blown from adjacent beaches. Dunes play an important role in many ecosystems by providing morphological and hydrological controls on biological gradients. Dunes are influenced by natural processes such as spit migration and aeolian activity, as well as by human activities such beach nourishment, construction of permanent structures, grazing and other human influences. However, migrating dunes can engulf houses, fields, settlements and transportation corridors.

Primary dunes are the first real substantial defense against overwash by storm waves and flooding. Natural dune formation and reactivation is very dynamic. They are repeatedly destroyed and rebuilt by natural processes. These dunes migrate naturally, maintaining their shape and form, while continually providing protection to the secondary dune system. Storm events and wave action are mechanisms for both destruction and construction of primary dunes. Net sediment transport on Fire Island is from east to west. Since the Fire Island Lighthouse was constructed 100 years ago on the westernmost point of the island, nearly five miles of barrier island have been added to the west forming what is now the Robert Moses State Park (Figure 2).

Secondary dunes are located further inland and generally are more long-term features than primary dunes. They support established vegetation which provides habitat for fauna. The Sunken Forest, a unique 300-year old holly and sassafras forest, is an example of the potential longevity of secondary dunes when their primary dunes have remained unaltered.

Human Influence

Changes in dune morphology and movements can result from variations in rainfall (drought cycles). Widespread dunal change can also be induced by changes in wind patterns and by human disturbance, such as alterations of beach processes and sediment budgets, destruction of vegetation cover by trampling or vehicle use, overgrazing, and the introduction of exotic species.

The entire barrier island once supported sand dunes comparable in height and width to the dunes found on the eastern part of the island. However, both natural forces of erosion and, more importantly, human development have reduced the continuous nature of natural dunes on Fire Island.

Most of the scoping meeting participants agreed that the dune systems at FIIS are have been altered from human interaction with the ecosystem, mainly as a result of beach replenishment and artificial dune construction. Beach replenishment (beach nourishment or beach resanding) is the process of adding sand to a beach from another source. This is usually done by pumping sand onto the beach from an offshore submarine location. Dune construction is accomplished by "beach scraping" in which bulldozers are used to push sand from the beache towards the front line of beach homes. The goal of this work is an attempt to reconstruct primary dunes eroded during storm events.

Residents of the island have basically eradicated the secondary dune system of the island by constructing homes and other buildings in their place. Natural recovery rate of dune systems is approximately five to ten years after dunes are destroyed by storm events. What takes nature five to ten years to recreate humans can accomplish in one day. Private citizens contract heavy equipment to rebuild dunes between their homes and the ocean in the hopes of protecting their homes from the next storm event. Alternatively, they can fund expensive beach replenishment projects to accomplish the same end.

Law enforcement personnel use all-terrain vehicles (ATV's) to carry out their work. In emergencies they travel over dunes, which damages fragile plants and impacts indigenous fauna such as piping plover. In response, Fire Island National Seashore has provided vehicle passage through dunes for emergency and protection personnel. Unfortunately, these cuts through the dune become points of overwash between the bayside and the ocean. Therefore, roads through the dunes are constructed in serpentine fashion or at low angles to disperse wave energy and discourage breaching.

Dune cuts clearly expose deep tap roots of native vegetation. Native vegetation stabilizes dune systems by developing deep roots which grow downward through the dune and help prevent erosion. However, residents have introduced exotic species by landscaping their homes with aggressive, non-native vegetative species such as bamboo. Residents often install sprinkler systems to water their landscaped yards causing roots to remain shallow, fanning out to collect water. These shallow root systems do not provide sufficient anchors to help prevent dune erosion.

Management Significance

Although these processes are occurring outside of NPS managed lands, the effect of manipulating the dune system has repercussions throughout the entire barrier island ecosystem. The park has been unable to challenge these privately funded projects. The threat of overwash and flooding drives residents to engage in beach scraping and beach replenishment. Beach scraping steepens the gentle slope of sand from the tide line onshore, and creates an unnaturally steep wall of sand which meets the incoming wave.

A steepened approach to the beach causes changes in wave height and perhaps in breaking wave direction. A steeper dune front may actually cause waves to break more intensely than natural dunes. The combination of these two effects could cause a more destructive wave and residents could actually be increasing their flooding risk by engaging in these activities. The perceived threat of flooding from the ocean is actually a misperception because breaches occur from the bayside not the oceanside of the island due to channel dredging which focuses water towards the backside of the barrier island.

3.3.2 Shoreline Position

Ecological Importance

Erosion and sediment accretion are ongoing natural processes along all coasts. Waves are the primary cause of sediment transport in the littoral zone and are the principal cause of most shoreline change. The Fire Island shoreline has a history of significant alteration by large storm events such as, hurricanes and nor'easters. Storms produce rapid erosion with much spatial variability along the island where different processes are occurring at different rates. The barrier island is being eroded and accreted at the same time without apparent loss of sand to the system. Although there is a Cretaceous sediment source offshore, the majority of sand appears to be locked up in the island itself. Fire Island appears to be a self-contained system which would continually renew itself if left in its natural state.

Storm events bring garnet and magnetite sand to the exposed shoreline. This sand is brought to shore from glacial sediment deposits, originating from a terminal moraine of the Laurentian glacial ice sheet 8,000-12,000 years ago. The effects of this sand to the ecosystem are not known, but it is suspected that lighter particles are blown away leaving the heavier garnet and magnetite to armor the lighter beach sand beneath.

Human Influence

Human activities can profoundly alter shoreline processes, position and morphology. The dredging of navigation channels, beach mining, and modification of river channels greatly alter sediment transport and deposition. Beaches and shorelines are manipulated by the installation of protective structures such as jetties to fix inlets in position, groins to capture sediment, and bulkheads to protect shoreline from erosion. The removal of backshore vegetation, and the reclamation or replenishment of nearshore areas also affect shoreline processes.

For example, a groin was installed to protect a water tower at Ocean Beach. The groin was constructed to protect the shoreline from erosion from currents, tides and waves. The effect of groin was to cause accelerated erosion downshore. This retreat of shoreline, termed a "hot spot", continued to migrate downshore through the barrier island system at the rate of one kilometer per year, holding the shape of an eight-foot scarp in the sand. Rough calculations estimate human-induced changes to shoreline position has resulted in approximately two meters of beach recession in the last 45-50 years.

Great South Bay can freeze over in winter. Occasionally ice is thick enough to support a vehicle. During freeze-over years, the bayside shoreline erodes when strong storms from the north blow ice into ridges which are rammed shoreward into marshes. As a result the bayside shoreline is retreating rapidly and certain communities no longer have any beach in front of their homes. In response communities have constructed revetments and walls. This has accelerated the erosion of the beach, and caused major damage to structures such as marinas, support piles, and piers.

Two inlets at Fire Island are currently maintained by the ACE, Moriches Inlet to the east, created by a hurricane in 1932, and Fire Island Inlet to the west. Under natural conditions, inlets at Fire Island have a life span of approximately 40-50 years. However, these inlets have an economic impact to the area and will remain open in perpetuity according to an NPS-ACE breach closure plan. Fire Island communities suffered through four storms in three years with 25-year recurrence intervals, which spawned the breach closure plan. The Fire Island communities generally believe that the NPS should close breaches as they occur. Opinion is that the system can handle only two inlets, and if another opened, one would close as a result of insufficient sand.

Sediment supply to Fire Island has been affected by the stabilization of Moriches Inlet in the 1950s. Once a jetty was constructed and the inlet deepened, the system shifted from flood-tidal dominance to ebb-tidal dominance which caused shifts in sand distribution. After placement of the jetty, the inlet created an offshore sand buildup which normally would have been transported to Fire Island. The system stabilized forty years later in the 1990s, and sand resumed movement down-current once again. During that time, Fire Island was robbed of sand by Moriches Inlet which affected the shoreline position extending down to the wilderness area. Initially the jetty created a total barrier to the movement of sand; in time, the buildup of sand created it's own natural barrier.

The Army Corps of Engineers routinely dredges the Fire Island Inlet. Moriches Inlet is dredged only when major issues of navigation become apparent. Maintenance of deep water shipping channels in many areas on the bay side of the island interferes with littoral processes. Dredged basins have created deep water within 100 feet of shore. Maintenance of near-shore basins and channels increases the amount of energy conserved by approaching waves and contributes to increased sediment suspension and coastal erosion. At Moriches Inlet the ACE dumped dredge spoils east of the natural sand barrier. Now it places the spoils west of the barrier to promote the east-west transport of sand.

Management Significance

Changes in shoreline position affect transportation routes, coastal installations, communities, and ecosystems. The effects of shoreline erosion on coastal communities and structures can be drastic and costly. It is of paramount importance for coastal settlements and managers to know if local shorelines are advancing, retreating, or stable.

Residents of Fire Island claim that structural protection such as the Westhampton groin field are causing erosion to the beach near their homes. Manipulation of the sand budget outside park boundaries, mainly by the ACE, is a cause of concern to managers due to the potential downshore effects. It is also a concern because it is still not clearly understood where the source of sediment is to supply Fire Island. All that is known is historically there was an outcrop similar to the one at Mastic Beach which no longer exists.

The deficit in the sediment supply budget could be coming from a Cretaceous supply offshore which is eroding to form sand ridges and then transported to the beach. USGS scientists have recently submitted a research proposal to help determine the deficit. Once known, the total supply of sediment to Fire Island will give managers the scientific data they currently lack for negotiating with outside agencies whose projects potentially affect the sediment supply to Fire Island. Currently park management is suffering from a lack of scientific information.

Outside agencies such as the ACE is looking at the potential of "mining" the offshore Cretaceous sand ridges as a sediment source for beach replenishment. If research shows this sediment is the missing source of sand to Fire Island, then to consume it now would be to rob the future beach of sand supply.

Nearshore conditions are associated with a trough, then a bar at shallow depth. Gaps in this bar create cuts which migrate downshore. One such gap caused overwash which created a major access problem on the island and presented a difficult management problem for FIIS.

There is a greater risk of overwash and flooding where dunes have been removed by humans. Overwash transfers large quantities of sand from the beach toward the interior of the island. Once the island is narrow enough, sand will actually be carried all the way across the island. This creates the "rollover" action of the barrier island. Large features develop where the transfer of sand is significant which causes very rapid shoreline position change. This would cause an obvious safety implication if vehicle access routes were blocked.

In the event a nor'easter or hurricane closes Moriches or Fire Island Inlet and the ACE, the business community, and the residents of Fire Island want to relocate the inlet, the park is obliged to do so based on mandates of the enabling park legislation.

It is difficult for the park to manage a naturally shifting, dynamic system in a static way. In an ideal world, the long-term goal of redistribution of ownership on Fire Island would be to relocate private homes to an area behind the primary dune system. However, even if boundaries of FIIS were redistributed to a lengthwise boundary such that the park managed the beachfront and primary dune systems, eventually the island would move. Since barrier islands tend to move towards shore, eventually the park would be managing aquatic resources.

3.3.3 Wetlands Extent, Structure, and Hydrology

Ecological Importance

Wetlands are areas of high biological productivity and diversity. They provide important sites for wildlife habitat and human recreation. Wetlands can serve as flood buffers and, in coastal zones, as storm defenses and erosion controls. Wetlands can affect local hydrology by acting as a filter, sequestering and storing heavy metals and other pollutants such as mercury.

Fire Island National Seashore protects an ancient Sunken Forest located between primary and secondary dunes. Here groundwater comes to the near-surface in an area behind the secondary dunes. The area supports unusual plants not seen anywhere else on the island. The reason the Sunken Forest exists is due to the intact secondary dune which protects it from salt pruning. While the island wouldn't have all looked like the Sunken Forest prior to human influence, the forest is a significant resource to the park.

Some wetland areas are vernal pools created by winter ice, snow, and spring rains. Others are supplied by high water tables coming to the land surface. Vernal pools are known to support annual herpetological populations.

Human Influence

Wetlands develop naturally in response to morphological and hydrological features of the landscape. Their evolution can be affected by external factors such as climate change, landscape processes (i.e. coastal erosion), or human activities such as draining for construction purposes. Bulkheading is used by private land owners on the bayside of the island to contain marsh and wetland areas and to stop erosion of private property. Home construction has destroyed wetlands and vernal pools on Fire Island. The effects of this on herpetological populations are currently being monitored. Small marshes have developed around artesian wells, a source of water for decades. The park has requested funds to cap the wells and restore surrounding areas to their original ecosystem.

Many residents regard wetlands and marshes as breeding grounds for mosquitos. A few decades ago, the best technology for reducing mosquito populations was ditching wetlands and marshes to discourage standing water and to encourage water movement. This practice was done at the William Floyd Estate and within the Otis Pike Wilderness Area. Today, spraying for mosquito control is done by the Suffolk County Vector Control for the benefit of the private landowners in the communities. Although there is some drift, the wetland areas are not systematically sprayed. The most popular pesticide used for mosquito control is Resmetherin.

Management Significance

Wetlands can provide important archives of past climatic, hydrologic, and vegetative changes. They will also exert a profound effect on future environments if presently sequestered materials are released, especially carbon dioxide and methane. The paleoecological record can provide baseline trends for use in developing models for future management approaches and for predicting consequences of environmental change.

Ditched marshes are influenced by tidal activity. These areas will receive passive restoration as sediment will eventually distribute evenly in the marsh. Restoring ditches in the wilderness area, however, requires active restoration. All restoration needs within the wilderness area must be accomplished using hand tools because heavy equipment and other machinery is not permitted within its boundaries. While restoration of marshes and wetlands is important to park managers, doing so without the use of machinery is an expensive and daunting task. Restoring ditches by hand in the wilderness area may not be a high enough priority to justify the funding required to carry out such a task.

The reed *Phragmites australus* is encroaching on spartina salt marshes and it is found everywhere on the island. It is unknown whether this is a result of human interaction. It is also unknown whether this is an indication of uncontrolled invasion of the marsh ecosystem. Historically, marshes and wetlands have been visually monitored by managers and there has been no indication of loss of ecosystem health such as a die-off of certain vegetation. However, many wetland areas on the south shore of Long Island are being lost to development. The remaining wetland areas probably represent only a remnant of what existed prior to man’s influence. This makes the wetland areas under NPS jurisdiction even more valuable to flora and fauna that depend on them for survival.

3.3.4 Relative Sea Level

Ecological Importance

Changes in relative sea level may alter the position and morphology of coastlines, causing coastal flooding, saturation of soils and a loss or gain of land. It may also create or destroy coastal wetlands and salt marshes, inundate coastal settlements, and induce saltwater intrusion into aquifers leading to salinization of groundwater. Coastal ecosystems are bound to be affected by increased salt stress on plants. A changing relative sea level may also have profound effects on coastal structures and communities. Low-lying coastal and island areas are particularly susceptible to sea level rise. It is estimated that 70% of the world's sandy beaches are affected by coastal erosion induced by relative sea level rise.

Development of the present coastline in the Fire Island region was due to the inherited landform (terminal moraine) and rising sea level. Barrier island and spits developed from the balance of sea level rise and wave energy. When sea level rise slowed, wetlands formed. The rise was gradual enough for vegetation to move upland in response.

Human Influence

Variations in sea levels are natural responses to climate change, tidal variations, isostatic rebound, tectonics and other earth processes outlined above. Relative sea level rise is causing changes in rate of compaction of barrier islands. Rapid withdrawal of groundwater can contribute to this process, but at Fire Island the groundwater is pumped from aquifers thousands of feet deep, and not from shallow groundwater lenses. Fluid withdrawal from deep sedimentary rock is not expected to contribute to relative sea level changes locally.

Management Significance

Climate change (global warming) may be partially responsible for rising sea level. However, the degree to which climate change is human induced is still in debate and controversial. The current data is suggestive, but not definitive. The NPS is not actively involved in climate change research. Therefore, it should continue to rely on research and data from the U.S. Geological Survey, the National Oceanic and Atmospheric Administration (NOAA) and other federal agencies and research institutions. NOAA maintains the Sandy Hook Tide Gauging Station. Discussions with these other agencies and institutions are vital when making management decisions. Climate change is a long-term park management issue and not one that can be dealt with at the park level. Yet, the impacts of climate change on shoreline parks are perhaps already being manifested by increasing beach erosion and by larger and more frequent storms.

3.3.5 Groundwater: Quality, Chemistry, and Level

Ecological Importance

Groundwater is the major source of water in many regions, supplying a large proportion of water globally. In the United States, more than half the drinking water comes from the subsurface. The availability of clean water is of fundamental importance to the sustainability of life. It is essential to know how long the resource will last and to determine the present recharge.

Groundwater is almost globally important for human consumption, and changes in quality can have serious consequences. It is also important for the support of habitat and for maintaining the quality of base flow to rivers. The chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation, and for industrial and other purposes. It also influences ecosystem health and function, so that it is important to detect change and early warnings of change both in natural systems and resulting from pollution. Changes in groundwater recharge rates have a direct relationship to water availability. The unsaturated zone may store and transmit pollutants. Releasing these pollutants may have a sudden adverse impact on groundwater quality.

Two groundwater lenses exist at FIIS. One is shallow, at a depth of several hundred feet. This source is not used for drinking or other consumptive use. The second lens exists at nearly 2,000 feet deep in sedimentary rock, and is the source of drinking water for residents of Fire Island.

Following winter, small vernal ponds appear in the spring when the groundwater table is high and then disappear in the summer months usually due to a drop in groundwater level and by evaporation. Vernal pools provide ephemeral habitat for many species including the endangered piping plover and various salamander populations which are known to breed only in vernal pools.

Human Influence

Pollution from septic systems is an important and little-understood human impact to the groundwater and to the ocean and bay ecosystems. All homes and businesses on Fire Island use septic systems which flush into the shallow groundwater lens. Currently, many communities have exceeded zoning regulations which prohibit construction densities over thirty percent. There is not only an increase in the number of homes currently being constructed, there is also an increase in the use of existing systems. The trend is for more homes being used year-round instead of primarily during the summer season. Fire Island is composed entirely of sand-sized material allowing easily percolation of water. It is unknown whether waste material from thousands of septic systems percolates into the Atlantic Ocean and/or to Great South Bay. Either event would negatively affect human populations. Also unknown is the effect of relative sea level change to groundwater. If groundwater levels rise with sea level rise, material from septic systems will also rise toward the surface creating a major sanitation problem in years ahead.

Management Significance

The scoping meeting revealed that the park does not have a great deal of research data on the groundwater system on the barrier island. The three geoindicators (groundwater quality, groundwater chemistry in the unsaturated zone, and groundwater level) were grouped and ranked together because of this lack of information. Group participants ranked these categories high for ecological significance, high for human influence, and moderate for management significance. Norm Ferris from Cape Cod National Seashore submitted a joint USGS-NPS project proposal to examine the effects of septic systems on shallow aquifers in selected Fire Island communities.

Under normal circumstances a large human population drawing groundwater for consumption would cause saltwater encroachment. Fire Island drinking water is drawn from too deep to cause saltwater encroachment. Groundwater extraction is normally of highest significance, but at FIIS it is not, and it has never been necessary to install monitoring wells. When Suffolk County drills a water well on Fire Island, it is allowed to flow unimpeded ("dewater") in order to remove debris and to allow the water to clarify. The water has been routinely allowed to flow into the bay. In a recent request, the county was not allowed to drain freshwater into the bay, but rather routed to the ocean side. Whether this will be a repeated occurrence is questionable.

3.3.6 Wind Erosion

Ecological Importance

At FIIS wind is largely responsible for shaping sand dune systems. Ocean winds carry sand inland until an obstacle such as beach grass interrupts the flow and the suspended material drops out. In a natural setting there would be no dune system without beach grass. Finer beach sand at Fire Island blows away leaving heavier sediments behind such as garnet and magnetite sand which essentially self-armors the Fire Island beaches.

Human Influence

Presently on Fire Island there are over four thousand homes, not including hotels, restaurants and condominiums. Placement of homes on the primary dunes has caused a shift in wind patterns on Fire Island. Humans have removed vegetation to create walkways between homes, boardwalk beach access, dune cuts, and the single-lane emergency vehicle road. These changes either disrupt normal wind patterns or concentrate its flow in a funneling effect. Areas formerly protected by vegetation are now exposed to erosion by wind. Buildings create physical barriers which stop wind flow and cause deflection and produce an eddy effect. Walkways and spaces between homes act like wind tunnels. An aeolian sediment budget prepared for the island showed wind tunneling from buildings caused specific, measurable erosion to sand dunes. All processes manipulate natural wind flow to scour and relocate sand and sediment out of its natural dune shape. Each contributes to artificial wind currents, eddies and tunnels.

Primary dunes in undisturbed dune systems move as whole units. The dunes provide habitat and protection for the dunes behind it. Home construction on primary dunes on Fire Island has resulted in dunes getting shorter and narrower. Flatter dunes invite overwash between bay and ocean water. At present, most primary dunes on Fire Island are becoming flatter as a result of shifted wind patterns, even in the Otis Pike Wilderness Area. Flatter dunes do not provide sufficient wind protection for dunes behind it, nor can they support deep-rooted vegetation.

Humans have eradicated the secondary dune system on developed parts of the island. It is unknown what changes will occur to the barrier island ecosystem as a result of this and other human manipulations to the sediment budget. Fire Island residents construct sand fences to capture migrating sand. This is a method used by residents to rebuild dunes in front of their homes. Fences are normally constructed in a “W” shape along the foredune and the primary dune line to capture and store wind-blown sediment.

Since beach replenishment often imports sediment from external areas, the material is usually different from naturally occurring sand on the beaches at Fire Island. This creates a sand compatibility problem. If the imported sediment is composed of a larger size or denser particles than natural beach sand, then individual particles cannot be transported as far away; if particles are lighter, wind carries them farther, resulting in the fractionalization of the beach sand.

Construction of homes has eliminated the “salt pruning” effect on vegetation and has allowed for unchecked tree growth. In natural dune systems, salt air and wind prunes vegetation to the height of the primary dune. Unchecked tree growth could have many unknown effects on shallow groundwater resources at Fire Island. An example of human interference is the Smokey Hollow Bog which formerly existed within a primary dune and swale area. Historic photographs of the area show a natural bog which supported cranberries. A home was built on the primary dune in front of the bog. The home created a physical barrier to the wind which formerly flowed over the bog to keep the vegetation low. Residents landscaped the yard with non-native tree species, which were protected from the wind by the house. As trees grew tall in the protection of the house they began to require more water, which they drew from the bog. In time the cranberry bog completely dried up.

Management Significance

Although wind erosion was ranked with high ecological importance, high human influence, it ranked low in management significance. Fire Island National Seashore managers find themselves in the position of treating the barrier island as a static entity in order to preserve infrastructure for its residents. In the past, the park has constructed dune fencing as a political gesture to the community. It was viewed by the park as a way to protect the roadway from eroding. The decision was made to construct fence line rather than implement beach replenishment. The park has also been compelled to construct fence line for safety and health reasons in order to prohibit visitors from using the dunes as restrooms.

3.3.7 Surface Water Quality and Streamflow

Ecological Importance

Surface water quality and streamflow are applicable only to the William Floyd Estate section of the park. The estate contains four man-made ponds, two streams, and marsh/ wetland areas. Clean water is essential to human survival as well as to aquatic life. Most water is used for irrigation, with lesser amounts for municipal, industrial, and recreational purposes. Water quality data are essential for the implementation of responsible water quality regulations, for characterizing and remediating contamination, and for the protection of the health of humans and aquatic organisms.

Streamflow directly reflects climatic variation. Stream systems play a key role in the regulation and maintenance of biodiversity. Changes in streams and streamflow are indicators of changes in basin dynamics and land use.

Human Influence

Ditching of wetlands for mosquito management was carried out to increase speed of water flow through the marshes and wetlands areas. The area surrounding the William Floyd Estate is densely populated and non-point source pollution is problematic for both surface water and streamflow quality. Enormous quantities of DDT were repeatedly dumped into the ponds, although not all ponds on the Estate were impacted by DDT application. DDT was applied for about 15 years, ending on Long Island in 1966 and totally banned by the EPA around 1972. DDT is a colorless insecticide which is toxic to man and animals when swallowed or absorbed through the skin.

Management Significance

Scoping meeting participants ranked surface water quality high for ecological importance, high for human influence, and low for management significance at the William Floyd Estate. Streamflow received three moderate rankings.

Flow lines from ponds and wetlands on the William Floyd Estate drain directly into Moriches Bay. The nutrient-rich and highly productive bay supports a commercial fishing industry, mostly for hard-shell clams, blue claw crabs, and blue mussels. Oysters disappeared in commercial quantities when Moriches Inlet was established in the mid-1930s, which raised the salinity. The fishing industry is at risk from point and non-point source pollution. The park investigated potential effects of removing the DDT in the pond sediments, and determined that to disturb the substrate would cause more harm than good. The study showed that the DDT was not migrating from its original location. So the DDT still remains at the bottom of the ponds and to date has not been detected within the Great South Bay.

3.3.8 Soils Quality; Sediment Sequence and Composition

Ecological Importance

As one of Earth's most vital ecosystems, soil is essential for the continued existence of life on the planet. As sources, stores, and transformers of plant nutrients, soils have a major influence on terrestrial ecosystems. Soils continuously recycle plant and animal remains, and they are major support systems for human life, as they determine the agricultural production capacity of the land. Soils buffer and filter pollutants, they store moisture and nutrients, and they are important sources and sinks for carbon dioxide, methane and nitrous oxides. Soils are a key system for the hydrological cycle. Soils also provide an archive of past climatic conditions and human influences. The chemical, physical and biological character of aquatic sediments can provide a finely resolvable record of environmental change in which natural events may be clearly distinguishable from human inputs.

Human Influence

Sediment deposition is a natural process which can be strongly influenced by human activities such as land clearing, agriculture, deforestation, acidification, eutrophication, and industrial pollution within the drainage basin or sediment catchment. The soil quality geoindicator applies only to the William Floyd Estate, where enormous quantities of DDT were repeatedly dumped into the ponds as described in the previous section.

Historic grazing has disrupted sediment sequence and composition over time. Selective grazing by animals can cause a gradual disappearance of grass species and an increase in more brushy species, with a tendency to develop increased space between plants.

Management Significance

Park managers don't know what changes have taken place in the sediment composition over time on Fire Island. Park personnel have discovered peat bogs which suggest that the bay side was once on the ocean side.

3.3.9 Slope Failure

Ecological Importance
Slope failure is a natural process which can be induced, accelerated, or retarded by human actions. At Fire Island very few naturally-occurring landslides exist on the dune systems, as the dynamic power of wind and waves prevent dunes from becoming oversteepened.

Human Influence
Small landslides occur on beach scarps created by humans following beach scraping. Slope failures are caused by unnaturally oversteepened dune construction. Lateral support of the man-made dunes is removed through the erosive power of waves and longshore and tidal currents.

Management Significance
Slope failure on reconstructed dune systems is a safety concern for park visitors and residents of Fire Island. The steep scarp which remains following a slope failure can be up to eight vertical feet.

4.0 Scoping Meeting Participants

Patchogue, NY April 24-25, 2001

Fire Island National Seashore Staff

Michael Bilecki, Chief of Resources Management & Planning
Jim Ebert, Biologist
Richard Stavdahl, Unit Manager, William Floyd Estate

Other National Park Service Staff

Brendan Cain, I&M Physical Scientist, Cape Cod National Seashore (CACO)
Robert D. Higgins, Branch Chief/Geologist, Geologic Resources Division, Denver, CO
Meredith Manning, Geologist, Redwood National and State Parks, Arcata, CA

U.S. Geological Survey

James Allen, Coastal Geomorphologist, Boston, MA

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6.0 APPENDICES

6.1 Appendix 1: Geologic Processes - Role and Importance in Ecosystems

The geosciences traditionally have not been integrated into land management or ecosystem planning, in spite of the importance of the physical environment to ecology. This is partly because traditional approaches to land management perceive the landscape as a web of biological processes playing out on an inert geological stage rather than perceiving the landscape as the interplay of many processes – biological, geological, and social – that are interrelated and interdependent. (See Figure 3 below).

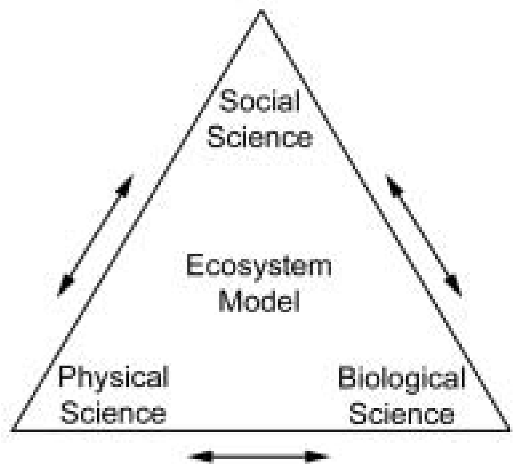

Figure 3. Relationship of component parts to an ecosystem.

Through the last two decades, the focus of land management has slowly been shifting from the former approach to the latter. This changing philosophy brings a need to devote increased attention to the geosciences, and especially to the interactions between geologic and biologic systems.

Geology is a major determinant of topography, water and soil chemistry, fertility of soils, stability of hillsides, and flow of surface and groundwater. These factors in turn determine where and when biological processes occur, such as timing of species reproduction and distribution of habitats. Likewise, biological processes affect geological processes. For instance, biological activity contributes to soil formation and soil fertility, controls hillside erosion, traps blowing sand to form sand dunes, stabilizes drainages, and attenuates floods.

A challenge in appreciating the relevance of geology is that geologists often work with very long relative time scales whereas life-scientists deal with much shorter time scales. However, geologic processes occur over a wide range of temporal and spatial scales from millions of years, such as mountain building, to processes that occur virtually instantaneously (and often catastrophically) such as floods, landslides, and earthquakes. Between these extremes are processes that are not easily pinpointed in time but are rapid enough that we can easily observe changes in geologic features as they occur. They may occur continuously or in repetitive cycles with long periods of inactivity. Examples of these are shoreline movement, river transport of sediment, soil formation, and cave development.

Geologic processes are as diverse spatially as they are temporally. Microscopically, adsorption of chemical elements to sediment particles may be a key process in determining groundwater chemistry. Globally, geothermal activity at Yellowstone National Park or Lassen Volcanic Park is related to the movement of tectonic plates. Geological processes that most directly impact biological processes include the following: stream and groundwater flow and their variations, erosion and deposition, weathering and mass wasting (landslides, rockfalls), earthquakes, and volcanic phenomena (eruptions, hot springs). These processes collectively operate on a variety of time scales, and the time scale of each process by itself may vary over time. It is possible for all of these processes to be operating at once in a single park. For example, an eruption in Hawaii Volcanoes National Park is usually accompanied by earthquakes (though minor) and can include landslides, stream diversion by lava flows, and buildup of topography when lava flows solidify. These processes destroy some habitats while creating others, and introduce new substrates for early successional stages, thus maintaining habitats for early successional species. Even on human time scales, the geological substrate for ecosystems is as dynamic and constantly changing as are the ecosystems themselves. One cannot understand ecosystem dynamics without also understanding the dynamics of their substrate. This type of human-scale geologic process also can impact the visitors to the parks by presenting potential hazards (Parrish and Turner, 2000)

What is viewed as a static geologic resource contributes to the ecosystem and biodiversity. For example, in Grand Canyon National Park, the nesting sites of the spotted owl are restricted to ledges formed in the Hermit Shale. Understanding why this rock layer is so important to the owls indicates the need for integrated biological and geological research. The Winkler's cactus grows only on the white, powdery soil and pebbles eroded from the Morrison Formation in Canyonlands National Park. In this case, not only is the distribution of the rock layer itself important to the plant, but the erosion products themselves are quite fragile, requiring management of both the plant and its delicate habitat.

The geologic resources of a park - soils, caves, fossils, streams, shorelines, springs, volcanoes, etc. - provide a set of physical conditions required to sustain the biological system. Interference with geologic processes and alteration of geologic features inevitably affect habitats. For example, channelization of the Virgin River in Zion National Park caused the channel to incise, lowering the groundwater table and reducing the habitat of floodplain obligate species (Smith, 1998; Steen, 1999). At Jean Lafitte National Historic Park and Preserve, land subsidence outside the park is raising the water level in the park inundating the swamp forest and reducing habitat for forest-dependent species (Sauier, 1994). Alternatively, a manipulation of a biological system can induce changes in the geologic system that, in turn, affects the biological system. When beavers are trapped to increase the density of hydrophobic shrub species, the river morphology and sediment transport capacity changes resulting in a redistribution of the dominate fish species.

6.2 Appendix 2: Human Influences on Geologic Processes in and Adjacent to National Park Units

The term "human influences" is the central theme for the second part of this GPRA goal. The term has purposefully been selected in order to explore the full breath of possibilities, both inside the park and external to the park boundaries. Adjacent land use, consumptive activities, administrative practices as well as public visitation all impact earth surface processes. The following are some examples of these uses and impacts.

6.2.1 Land Uses (Adjacent to Parks)

- Agriculture – intense use can cause loss of soil, erosion, and dust storms. Use of pesticides can affect both surface and groundwater quality.

- Grazing – overgrazing can cause loss of vegetation, soil erosion and create conditions conducive to fires and the spread of non-native species.

- Forestry – intensive logging or clear cutting creates conditions for increased erosion; sediment that is lost increases sediment loading in streams, affecting aquatic habitats.

- Water Impoundment – Impoundments may affect one segment of a stream or river or the entire watershed. Controlled flow does not duplicate natural events such as floods and drought. It can affect the water temperature, sediment load, stream morphology and habitats that are dependent on natural flows in a fluvial system.

- Urbanization – This can cause a host of influences, including changes in drainage patterns, increased runoff and erosion, effects on surface and groundwater quality and quantity, release of toxins into the air and water, and increased humidity in arid regions.

- Shoreline Modification - Dredging, beach mining of sand, river modification, installation of hard structures (armoring), removal of back-shore vegetation, and alterations of the nearshore environment can potentially alter shoreline processes, position and morphology by changing the sediment supply.

6.2.2 Consumptive Uses

- Groundwater withdrawal – In instances where groundwater is depleted to the point where recharge cannot keep pace with withdrawals, the groundwater-dependent ecosystem is affected. Where withdrawal has been intense for a number of decades, the surface has subsided by as much as 10 feet over large areas.

- Oil and gas production – In rare instances hydrocarbon withdrawal can result in surface subsidence. More commonly, production operations result in contamination of surface waters and of subsurface aquifers and caves.

- Mining – Surface mining can reconfigure the landscape over large areas bringing significant and permanent change. It can affect the surface and groundwater by releasing heavy metals or other chemicals into the system, as well as affecting the groundwater level by dewatering pits. The quarrying of stone, mining of gravel and removal of soil, can impact geologic processes by the large volume of material that is removed. Underground mining can result in surface subsidence as well as health and safety issues.

6.2.3 Administrative Uses

- Roads and bridges – Often these have been constructed with little or no consideration for natural processes. Roads can disrupt drainage, cause erosion and create slope instability. Abutments for bridges can change the flow and morphology of streams and rivers.

- Parking Lots – Large paved areas inhibit infiltration and increase runoff. Water flowing from parking lots can cause erosion and gullying. Runoff of pollution effects surface and groundwater.

- Facilities Over Caves – Contaminants from restrooms and other water usage, plus runoff can reach caves and karst systems below causing damage to the fragile subterranean ecosystems.

- Water Consumption – In arid and semi-arid environments, water is a scarce and critical resource. Withdrawal of water may have significant impacts on the ecosystems, such as riparian zones.

- Trails – If they are poorly located with respect to soil, rock and vegetation considerations, they have the potential to exacerbate erosion, rock falls and slope instability.

- Exotic Species – Replacing native species with non-native species can have a significant effect on erosion and sedimentation processes.

6.2.4 Visitor Use

- Soil Compaction – Extensive visitor use often results the compaction of soil reducing soil productivity and increasing erosion.

- Social trails – Unplanned trails can seriously damage fragile resources such as in caves, wetlands, cinder cones, tundra, and areas having microbiotic crusts.

- Damage to Geologic Features – A number of geologic features are extremely fragile. They may take years to form but can be irreparably damaged or destroyed by visitor contact. Examples include stalactites and stalagmites in caves, erosional features, such as arches, bridges, hoodoos, badlands, and delicate crystals.

- Power Vehicles – Power boats, personal water craft (PWC), off-road vehicles, and snowmobiles are having a profound detrimental impact on park resources. Over a period of time, wakes from boats and PWCs result in shoreline erosion as well as air, water and noise pollution.

6.3 Appendix 3: Geoindicators – A Tool for Assessment

Geoindicators are measures (magnitudes, frequencies, rates, and trends) of geological processes and phenomena occurring at or near the Earth's surface and over a period of 100 years or less (Berger and Iams, 1995). They measure both catastrophic events and those that are more gradual, but evident within a human life span. Geoindicators are not geologic processes. However, there is a strong correlation between the two. Because geoindicators represent a landscape measurement, one that concentrates on physical processes and their interactions with biologic and human components, they are uniquely suited to assess human vs. natural causes of change in the ecosystem. Some are single parameters but most are aggregates of several measures such as groundwater quality. Examples include streamflow and channel morphology, groundwater level, soil and sediment erosion, frozen ground activity, lake level and salinity, and slope stability.

Geoindicators describe processes and environmental parameters that are capable of changing without human interference, though human activities can accelerate, slow or divert natural changes (Goudie, 1990a; Turner *et al*., 1990). Humans are an integral part of nature and the environment, but it is essential to recognize that nature and the environment are changing at one temporal and spatial scale or another whether or not people are present. Environmental sustainability must therefore be assessed against a potentially moving background. Table 2 is a checklist of 27 geoindicators developed by the International Union of Geologic Sciences through its Commission on Geologic Sciences for Environmental Planning. It is from this table that Table 1, specific to Fire Island, was developed.

Table 2. Geoindicators: Natural vs. Human Influences, and Utility for Reconstructing Past Environments.

Geoindicator	Natural Influence	Human Influence	Paleo Reconstruction
Coral chemistry and growth patterns	H	H	H
Desert surface crusts and fissures	H	M	L
Dune formation and reactivation	H	M	M
Dust storm magnitude, duration and frequency	H	M	M
Frozen ground activity	H	M	H
Glacier fluctuations	H	L	H
Groundwater quality	M	H	L
Groundwater chemistry in the unsaturated zone	H	H	H
Groundwater level	M	H	L
Karst activity	H	M	H
Lake levels and salinity	H	H	M
Relative sea level	H	M	H
Sediment sequence and composition	H	H	H
Seismicity	H	M	L
Shoreline position	H	H	H
Slope failure (landslides)	H	H	M
Soil and sediment erosion	H	H	M
Soil quality	M	H	H
Streamflow	H	H	L
Stream channel morphology	H	H	L
Stream sediment storage and load	H	H	M
Subsurface temperature regime	H	M	H
Surface displacement	H	M	M
Surface water quality	H	H	L
Volcanic unrest	H	L	H
Wetlands extent, structure, and hydrology	H	H	H
Wind erosion	H	M	M

H – HIGHLY influenced by, or with important utility for
M – MODERATELY influenced by, or has some utility for
L – LOW or no substantial influence on, or utility for

Note: This table illustrates in a general way the relative roles of natural and human-induced changes, both direct and indirect, in modifying the landscape and its geological systems. However, it excludes from consideration influences that may be brought about by anthropogenically induced climate change.

6.4 Appendix 4: Description of Geologic Processes

6.4.1 Geologic Processes vs. Geoindicators

Geoindicators are parameters that can be used to assess changes in rates, frequencies, trends, and/or magnitudes in geological processes. The following are three examples illustrating the difference between geologic processes and geoindicators using glaciation, volcanism, and coastal processes.

Glaciation is the process by which ice accumulates, flows, and recedes, shaping the land surface over which it moves. Glacier fluctuations, in the geoindicator sense, are changes in ice mass balance and position that are important to track in understanding and forecasting changes to "cryospheric" mountain ecosystems and associated fluvial systems.

Volcanism is the process whereby magma reaches the surface and erupts to shape the surrounding landscape. This may occur as lava flows, ash falls, explosive activity, etc. Volcanic unrest is the geoindicator that takes into account all the various kinds of changes that occur prior to and during an eruption, including geophysical, geochemical and tectonic.

Coastal processes include coastal erosion and deposition, barrier island formation and movement, wave patterns, nearshore currents, and coastal morphology. Shoreline position is the geoindicator that helps to assess the cumulative effect of these processes. Relative sea level is a simple measure that relates coastal subsidence and uplift, and changes in sea surface elevation due to glacial melting, thermal expansion of seawater, isostatic rebound, and tectonics.

6.4.2 Thresholds

The concept of thresholds, as it applies to geologic processes, is especially important to the land manager. When considering the maintenance of a healthy ecosystem, the passage of any number of components of that system across a threshold may irreversibly affect the system. A geologic system, landform, or feature could reach a point where drastic and irreversible change occurs. It also greatly influences where we place our need for further information, monitoring and study.

Geomorphic thresholds were defined initially as the condition at which there is significant landform change without a change of external controls such as base level, climate, and land use (Schumn, 1979). This definition has been expanded to include abrupt landform change resulting from progressive change of external controls. For example in a geologic system such as a stream channel, a change in runoff conditions may not always produce slow, continuous response. When the geomorphic system reaches a threshold or failure point, a short period of drastic change may occur. And the result may be, for example, a catastrophic slope failure. There is great difficulty in recognizing a threshold before it is reached.

6.4.3 Geologic Processes

The geologic processes operating on the landscape may be divided into two types, exogenic and endogenic. Exogenic processes are those that operate at or near the earth's surface. These processes have a number of agents like wind, water, and ice that cause erosion and deposition and include very basic processes such as mass wasting and physical & chemical weathering. Endogenic processes are generated within the earth's crust and mantle and include volcanism and tectonism (Toy and Hadley, 1987). These processes shape the configuration of the earth's surface (Easterbrook, 1969).

Fluvial Erosion and Deposition

The precipitation that falls on the earth either runs off the surface, soaks into the ground, or evaporates back into the atmosphere. That portion which runs off the surface of the land eventually collects into rivulets, gullies and streams which continuously erodes the land and deposits material elsewhere. Landscapes sculptured by fluvial erosion and deposition bear characteristic features that differ from those developed by other processes. Oxbows, point bars, alluvial fans, and deltas are but a few examples.

Glacial Erosion and Deposition

Glacial processes also produce unique landforms, such as kames, eskers, drumlins, various kinds of moraines, rouches moutonnêes, and many others. Glaciers move more slowly downslope than do streams, but are nevertheless capable of carrying large quantities of material derived by erosion from valley sides and bottoms. Glaciers produce the classic "U" shaped valleys of glaciated areas, as well as horns, arêtes, and cirques. Frozen ground features include such things as pingos, patterned ground, and solifluction ridges.

Groundwater Solution and Deposition

Some of the precipitation that falls from the atmosphere seeps into the ground, where it is stored until it emerges along valley sides and floors, lakes, bays and oceans. While in contact with rock material, groundwater promotes solution and other types of chemical weathering. Transport of weathered and dissolved material leads to development of unique landforms (caves and karst), especially in areas of soluble rocks, such as limestone. Heating of groundwater may result in hot springs, geysers, paint pots, and frying pans, as well as produce siliceous sinter deposits and promote diatom activity.

Mass Wasting

Mass wasting is the downslope movement of soil and rock material under the influence of gravity without the direct aid of other agents, such as water, wind, or ice. Water and ice, however, are frequently involved in mass wasting by reducing the strength of rock and soil and by contributing to plastic and fluid behavior of soils. Mass wasting is capable of transporting large quantities of material from hill slopes to valley floors. Mass wasting can be rapid, for example a rock fall or landslide, or slow as in soil creep.

Lacustrine and Oceanic Processes

Shorelines of oceans, seas and large lakes are modified continuously by the abrasive action of waves beating against the shore and deposition of material by wave and current action. Terraces, spits, bars, turbidity deposits and other features result from these processes.

Eolian Processes
Wind is a less vigorous agent of erosion, transport, and deposition of material than water, but in arid and semiarid regions, or areas having an abundant supply of unconsolidated sand, wind is locally an important agent producing yardang, ventifacts, lag deposits, loess deposits, and dunes. Sand dunes are the main attraction in park units such as Great Sand Dunes National Monument, Colorado, and White Sands National Monument, New Mexico.

Weathering
Mechanical disintegration and chemical decomposition of rocks cause them to be broken down into smaller pieces. In those areas where rocks offer differing resistance to weathering, differential weathering etches out weaker rock zones producing bizarre honeycomb patterns, and coupled with other agents of erosion can cause valleys to develop. In areas where mechanical weathering is dominant, the topography develops angular hill slopes, whereas in areas dominated by chemical weathering, smooth, rounded slopes are developed.

Volcanism
Eruption of lava on the surface produces very distinctive landforms, which if not too old, are easily recognized, such as at Craters of the Moon National Monument, Idaho, Lava Beds National Monument, California, and El Malpais National Monument, New Mexico. These include such features as shield volcanoes, strato- or composite volcanoes, cinder cones, various kinds of lava flows, tumuli, hornitos, pressure ridges, spatter cones and ramparts, lahar deposits and many more.

Tectonism
Deformation of the earth's crust caused by tension, shear, and compression may produce initial small scale landforms like fault scarps and sag ponds or produce huge regional scale folding or thrusting that only become exhumed by erosion later. Among common topographic features produced initially by tectonic movement are scarps, horsts, and grabens. Fault gouge is more easily eroded than unfractured rock, which can hasten the process of erosion. Relief of pressure from faulting can result in decompression melting, dike emplacement, and even volcanic eruption. Tectonism is a process that frequently is working in concert with other processes.